BRADLEY A3 (BLOCK 1) DVE FLIR ENHANCEMENT PROJECT THERMAL LOAD ANALYSIS (U)

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(U) Virtual modeling plays an important role in design of systems and subsystems. It is emphasized throughout the acquisition process and lifecycle. Modeling decreases prototype and testing costs and allows the designer to compare several options or solutions. The tools available for thermal modeling provide the capability to evaluate a design concept in a virtual thermal environment taking into account environment and vehicle induced conditions. MuSES (Multi-Service Electro-optic Signature) greatly simplifies the modeling process and makes it possible to model the complete vehicle system. MuSES obtains the model's thermal solution using a finite difference approach. This solution technique reduces computing resource requirements and operator expertise as compared to Computational Fluid Dynamics. Resulting system models can now incorporate electronics and crew thermal footprints in conjunction with power train and environmental sources.

(U) The Bradley A3 Block 1 is undergoing an upgrade. The vehicle is being fitted with a Drivers Vision Enhancement (DVE) Forward Looking Infrared (FLIR) unit to enhance the driver's vision. The sensor chosen for the upgrade has an operating temperature of 120 F. There is some concern that the temperature in the ballistic housing will exceed 120 F during extreme operating conditions.

(U) This paper presents a study performed on the Bradley DVE FLIR sensor and ballistic housing. The study determines if the internal temperature of the housing will exceed the operating temperature of the DVE sensor during extreme operating conditions. Presented below are the results of the parametric study. The model incorporates the effects of solar loading and ambient temperature energy sources in its evaluation.

(U) Introduction

(U) The overall objective of the study is to estimate the internal air temperature of the ballistic housing for the newly incorporated DVE FLIR on the Bradley Fighting Vehicle. Due to the limited airflow through the ballistic housing, there is a concern that the internal air temperature would

exceed the maximum operating temperature of the sensor during extreme conditions thus causing a failure. Therefore, the focus of the study is the internal air within the ballistic housing.

(U) To predict if the sensor is in jeopardy, the authors generated a model in MuSES to simulate the environmental and vehicle conditions that influence the sensor. To establish confidence in the results, a comparison to real data will validate the model. Once the model proved to be accurate within reason, the authors performed additional runs allowing extrapolation to the desired extremes.

(U) Model Approach

(U) The authors used geometry from a BRL CAD file, meshed in Eclectic, to create the model used within MuSES. The model includes geometry for the entire vehicle including the crew, the engine, and all internal electronics [1]. The model also has geometry representing the ballistic housing for the DVE FLIR sensor, and the sensor support hardware.

(U) The weather files for the test runs were generated using data collected from weather stations. The data used to validate the model was collected at KRC on December 1, 1992. The data used for the July 29, 2003 and July 30, 2003 model runs was collected at Selfridge Air National Guard Base (SANG). The data from SANG did not include solar radiation or long wave infrared measurements. Therefore, the model predicts the values for these two parameters. The KRC data included solar radiation and long wave infrared information that the model used for calculations.

(U) The team performing the engineering modification for the Bradley performed a field-test at SANG July 29 and 30 2003. The field test provided soldiers the opportunity to test the performance of the DVE FLIR. The authors used this opportunity to collect limited temperature data via thermocouples to use for comparison against the simulated results.

(U) Validation

(U) The model validation used actual data from weather and thermocouple measurements collected on 12/01/92 [2]. The weather data was used to create a weather file for MuSES. Three data points were chosen randomly to compare the modeled results against the measured data. The location of the data points are shown in Figure 1. The three points chosen are as follows: the top aft crew hatch, the front engine access hatch, and the engine hot air exhaust grill. The comparison plots for the former are located in Figures 2, 3, and 4. The discussion of the plots will be broken into two sections, before 2:00 PM and after 2:00 PM. Table 1 provides the temperature difference data before 2:00 PM while Table 2 provides the same data after 2:00 PM. Although the ballistic shroud for the DVE FLIR did not exist in 1992, the authors assumed that if the temperatures of other components on the vehicle match the modeled data, it would validate the model.

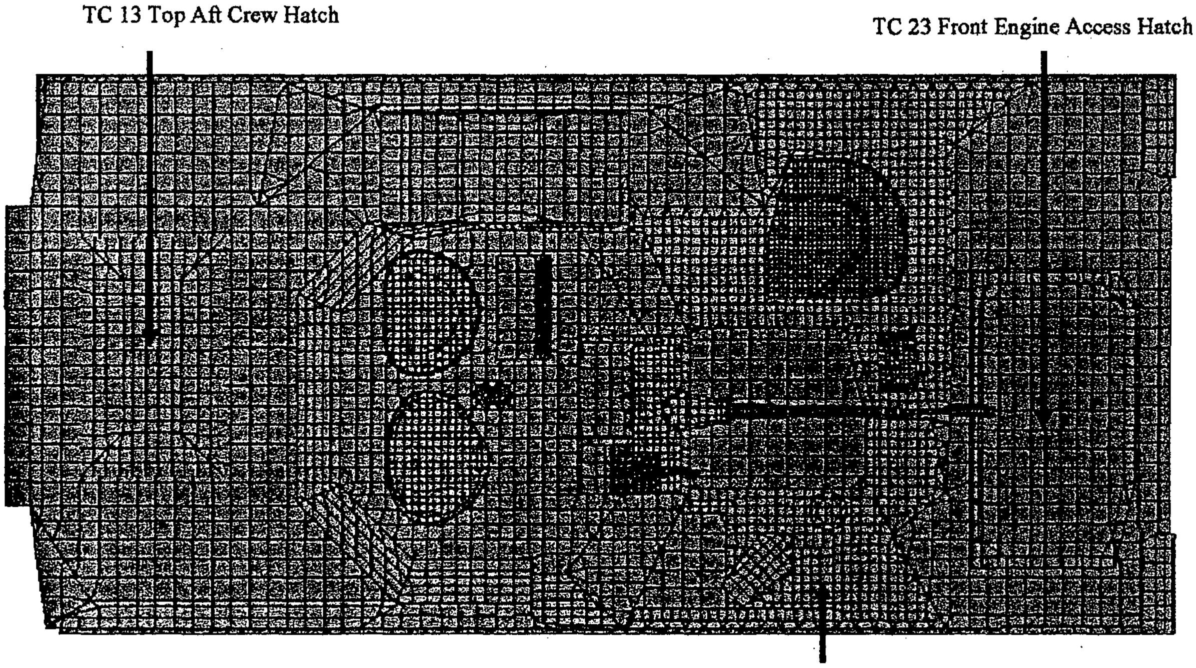

Figure 1: KRC Data Thermocouple Locations.

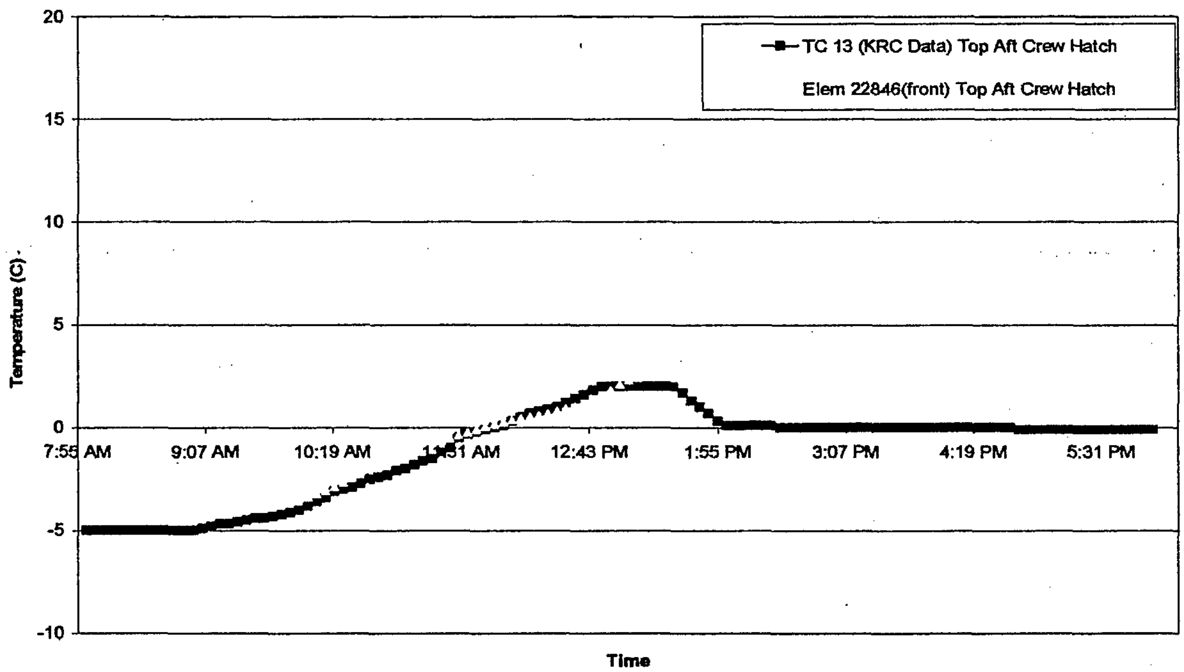

Figure 2: Top Aft Crew Hatch (MuSES) vs. Top Aft Crew Hatch (KRC).

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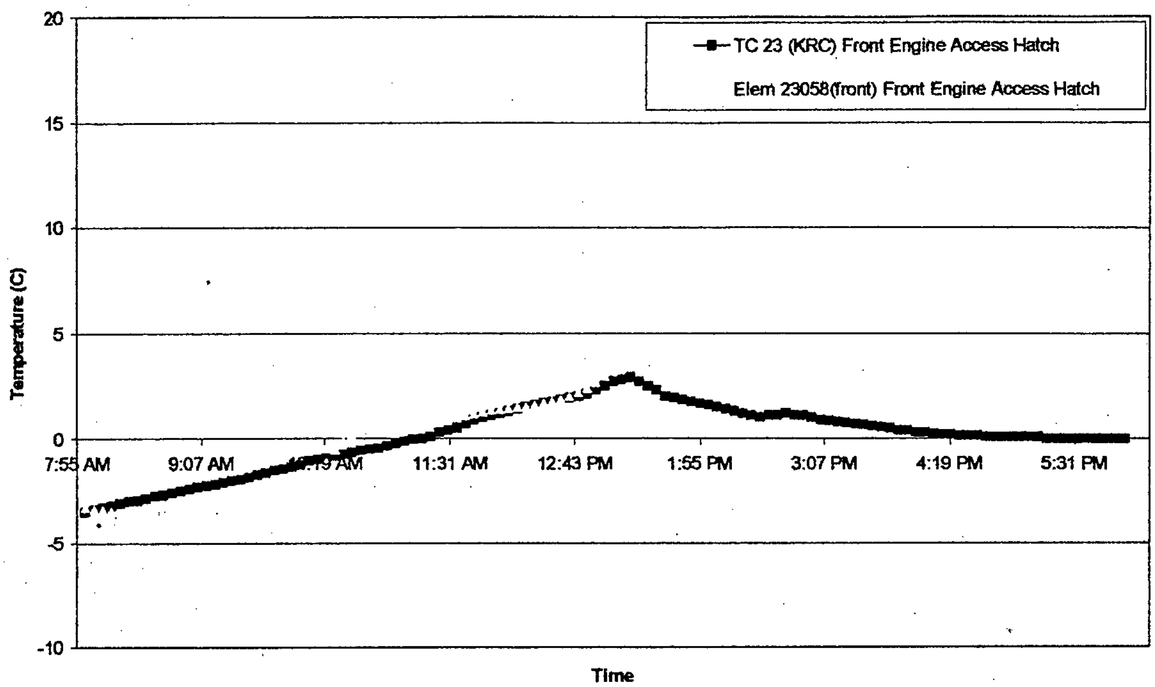

Figure 3: Front Engine Access Hatch (MuSES) vs. Front Engine Access Hatch (KRC).

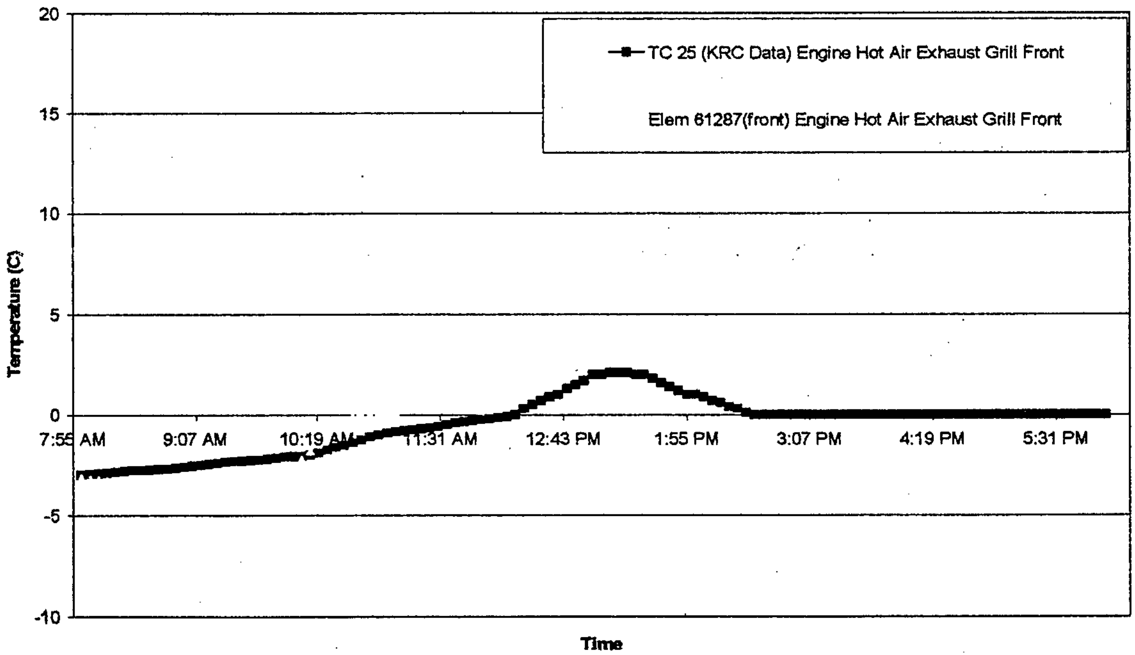

Figure 4: Engine Hot Air Exhaust Grill (MuSES) vs. Engine Hot Air Exhaust Grill (KRC).

(U) Before 2:00 PM, the general trend of the three chosen data points matched very well with the modeled data. The three locations where measurements were taken, matched within one degree or less with the modeled data. After 2:00 PM, the predicted temperature for all three chosen data points deviated with the measured data. To determine the reason for the discrepancy, the authors reviewed the test log for the field test data and discovered that at 2:00 PM it started to snow. The weather file for the model did not include precipitation of any form. The snow increased the heat transfer rate of the vehicle components and uniformly cooled exposed surfaces to 0 C (See Figures 2-4). Overall, the validation results provide confidence in the predictive capability of the model and support the legitimacy of the results discussed below.

Table 1: Temperature Statistics before 2 PM for the three data points.

	Top Aft Crew Hatch (TC 13) Before 2 PM (Figure 1)	Front Engine Access Hatch (TC23) Before 2 PM (Figure 2)	Engine Hot Air Exhaust Grill Front (TC25) Before 2 PM (Figure 3)
Average Temperature Delta	0.8 C	0.8 C	1.0 C
Minimum Temperature Delta	0.0 C	0.0 C	0.1 C
Maximum Temperature Delta	1.8 C	1.9 C	1.5 C

Table 2: Temperature Statistics after 2 PM for the three data points.

	Top Aft Crew Hatch (TC 13) After 2 PM (Figure 1)	Front Engine Access Hatch (TC23) After 2 PM (Figure 2)	Engine Hot Air Exhaust Grill Front (TC25) After 2 PM (Figure 3)
Average Temperature Delta	1.2 C	1.3 C	1.4 C
Minimum Temperature Delta	0.7 C	0.7 C	0.9 C
Maximum Temperature Delta	1.8 C	1.7 C	1.8 C

(U) Results

(U) On July 29th and 30th of 2003, a field test to demonstrate the DVE FLIR took place at Selfridge Air National Guard Base in Harrison Township Michigan. A thermocouple recorded the air temperature inside the DVE FLIR ballistic housing. Weather data collected by the Selfridge weather team provided inputs to the MuSES weather file. Thermal couple data was compared to the modeled data. The modeled data follows the general trend of the thermal couple data, as seen in Figures 5 and 6 below. However, several discrepancies are noted. Table 3 and Table 4 show the average temperature difference between the modeled and measured temperature for the internal air of the ballistic housing.

(U) For July 29, during the time span of 10:50 AM to 2:50 PM the correlation of the data was good, ranging from 0.2 to 0.7 degrees difference. In the morning and the late afternoon, the data correlation was significantly worse. The average delta of the temperature for the entire time, 9:25 AM to 5:00 PM was 1.4 C. For July 30, during the time span of 8:00 AM to 12:40 PM the correlation of the data was good, ranging from 0.7 to 1.7 degrees difference. During the early afternoon, the data starts to show some variation and this continued until the end of the test day. The average delta of the temperature for the entire time, 8:00 AM to 6:00 PM was 2.1 C.

(U) The time spans called out in Tables 3 and 4 correspond to the fluctuations in the plot between the modeled and measured data. Separating the plots into the different sections aided analysis. The times the engine was running and turned off is imposed on the plots in Figures 5 and 6 to provide insight into the correlation between significant data changes and the engine on/off cycle.

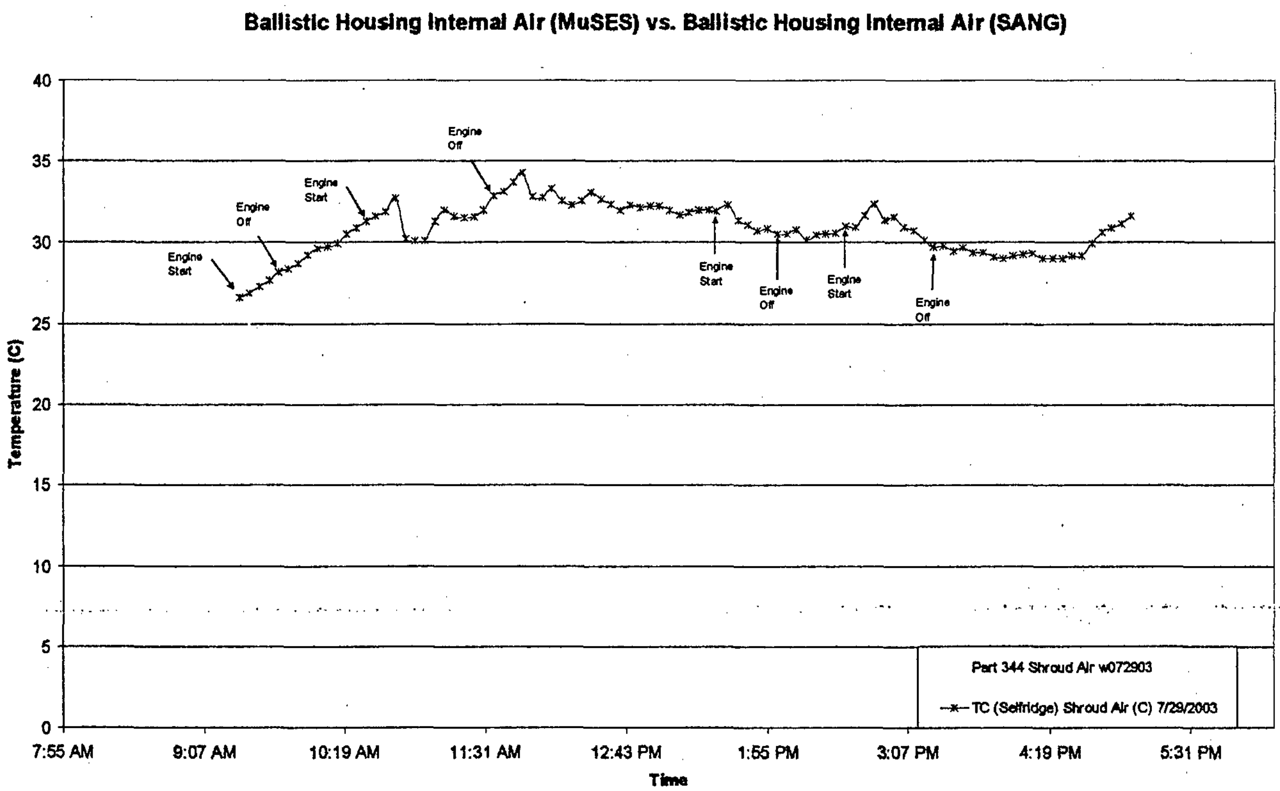

Figure 5: Shroud Internal Air (MuSES) vs. Shroud Internal Air (SANG) from July 29, 2003.

(U) As seen in Figure 5 and Table 3, from 9:25 AM to 10:45 AM and from 2:55 PM to 5:00 PM, the measured and modeled data do not correlate well. The average delta of the temperature is 2.3-2.5 C during those periods. The measured temperature was higher than the model predicted in the morning and lower than the model predicted in the afternoon. The authors are still investigating why this discrepancy occurred.

Table 3: Average Temperature Statistics for July 29, 2003.

Time	Average Temperature Delta Between Modeled and Measured Ballistic Housing Internal Air for 7/29/03 (Figure 4)
9:25 AM - 10:45 AM	2.3 C
10:50 AM - 11:30 AM	0.3 C
11:35 AM - 12:35 PM	0.7 C
12:40 PM - 1:35 PM	0.2 C
1:40 PM - 2:50 PM	0.7 C
2:55 PM - 5:00 PM	2.5 C

Table 4: Average Temperature Statistics for July 30, 2003.

Time	Average Temperature Delta Between Modeled and Measured Ballistic Housing Internal Air for 7/30/03 (Figure 5)
8:00 AM - 9:05 AM	0.7 C
9:10 AM - 11:20 AM	1.7 C
11:25 AM - 12:40 PM	1.7 C
12:45 PM - 3:50 PM	2.7 C
3:55 PM - 6:00 PM	2.9 C

(U) From 10:50 AM to 2:50 PM, the measured and modeled data correlate very well. The average delta of the temperature is 0.5 C during that period. The measured data has several spikes above the modeled results, but matches closely otherwise. The measured and modeled data is nearly identical during a portion of the time. The measured data drops below the modeled data then rises back to being almost equal at the end of the period.

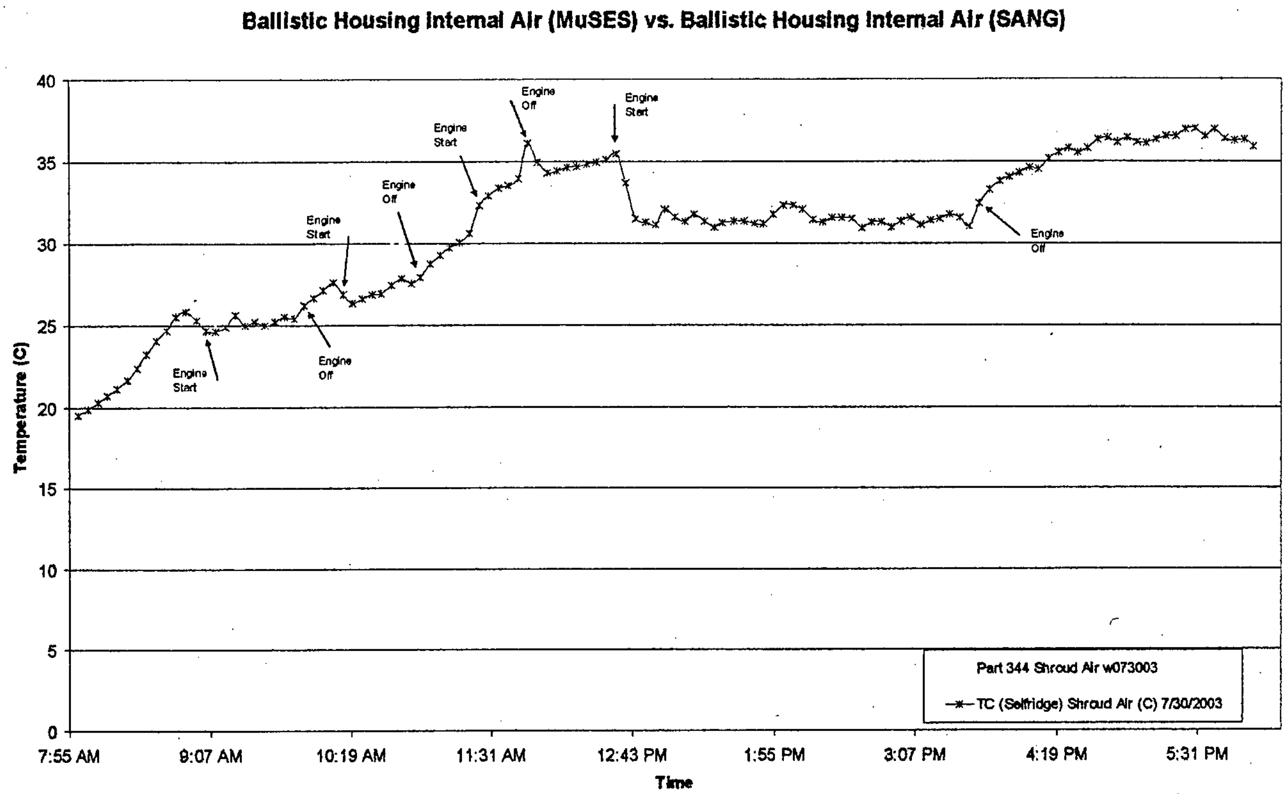

Figure 6: Shroud Internal Air (MuSES) vs. Shroud Internal Air (SANG) from July 30, 2003.

(U) As seen in Figure 6 and Table 4, from 8:00 AM to 12:40 PM, the measured and modeled data shared a general trend. The average delta of the temperature is 1.4 C during that period. The data is nearly identical for about thirty-five minutes then the measured data slowly spikes above the modeled data. For the next two hours, the measured data is lower than modeled data then rises back above the modeled data for an hour before it returns to being nearly equal.

(U) From 12:45 PM to 6:00 PM, the measured and modeled data do not correlate well. The average delta of the temperature is 2.8 C during that period. The measured data drops and holds around 2.5 degrees below the modeled data, then rises back to nearly equal and continues to rise above the modeled data for the rest of the afternoon.

(U) The thermocouple data showed that the engine operating cycle might have an impact on the internal air within the ballistic housing. During the July 30 test, when the engine was running the internal air within the ballistic housing would decrease in temperature as seen for the period of 12:35 PM to 3:40 PM (Figure 6). When the engine was shut off, the internal air within the ballistic housing would increase in temperature as seen for the period of 3:45 PM to 6:00 PM (Figure 6). To comprehend the true meaning of the data, an understanding of the engine compartment physics is necessary.

(U) When the engine is running, the fan is drawing ambient air into the engine compartment. The combustion process consumes some of the air drawn into the engine, while the remainder helps cool the engine compartment. As the air passes over the bulkheads and engine components, heat is convectively transferred to the air and then is blown out through the exhaust grill. When the engine is shut down, the fan no longer draws in the cooler ambient air. As a result, the engine compartment heats up quickly. The hot buoyant air exits the engine compartment through the intake grill.

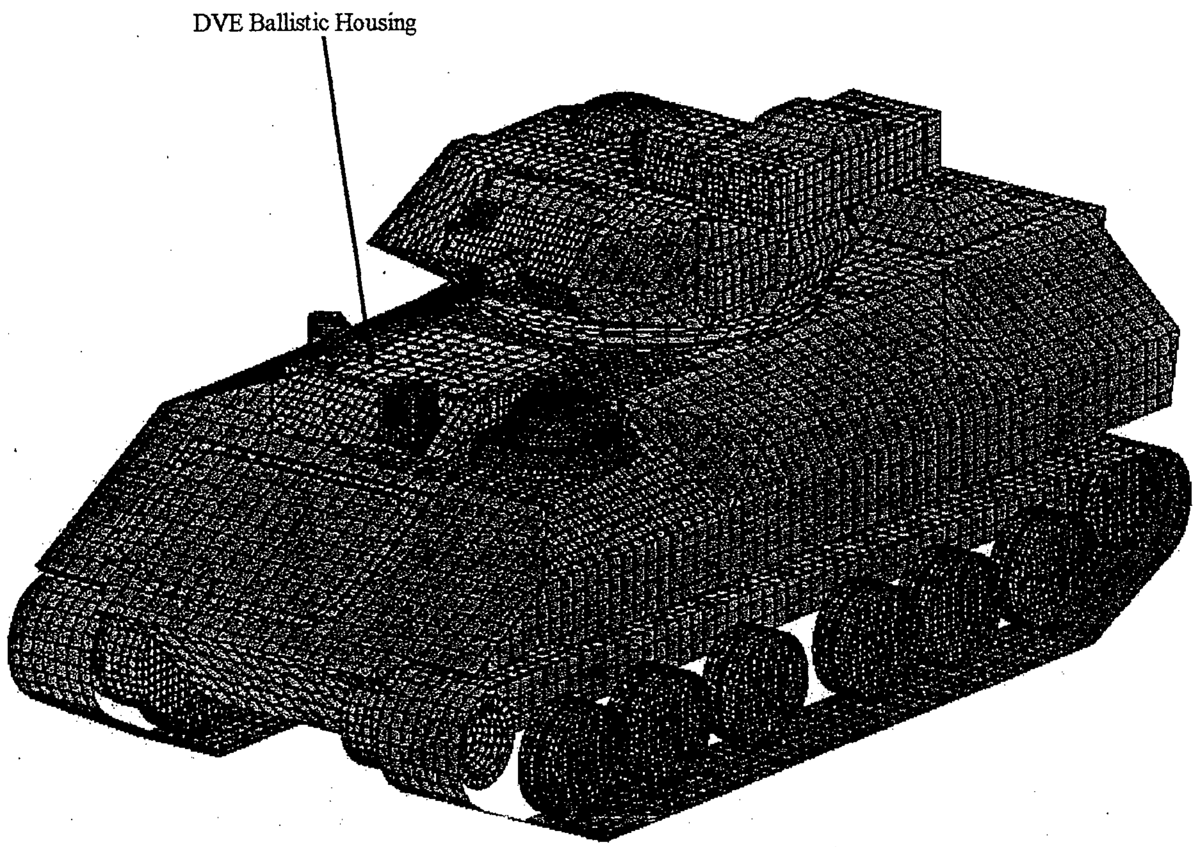

Figure 7: DVE Ballistic Housing Location.

(U) The ballistic housing sits above the engine compartment (Figure 7). A two-inch hole was drilled into the hull to route the necessary electrical cables. The hole exposes the internal air within the shroud to the engine compartment air. Therefore, when the engine fan is running, it draws cooler air through the ballistic housing. When the engine fan is not running, the hot buoyant air travels into the ballistic housing through the hole via natural convection. On July 30, for the period of 12:35 PM to 3:40 PM (Figure 6) a decrease of two degrees is experienced within the ballistic housing when the engine is running. When the engine is shut off, and natural convection begins, an increase of two degrees is experienced within the ballistic housing.

(U) Conclusion

(U) The modeled data was surprisingly accurate considering it only reflected some of the parameters affecting the vehicle. The model included solar loading and the ambient temperature interaction with the vehicle, but lacked the interaction of the engine run cycle and the subsequent heating. To achieve a more accurate prediction, the model must include a high fidelity engine geometry and the on and off cycle engine compartment physics. Once a high fidelity engine representation is in place, the model can be used to extrapolate data for extreme operating conditions such as a desert. Producing those types of results is the next step.

(U) References

[1] Perez, J., Jones, J., and Rogers, P. Development of a Practical Holistic Vehicle Thermal Model. In Proceedings, 13th Annual Ground Vehicle Survivability Symposium.

[2] RD&E Center Technical Report Number 13580, Baseline Thermal Data Collection for the M1 and M2, Fall 1992 at KRC, R. K. Baratono, Keweenaw Research Center, Michigan Technological University, Houghton, MI, 13 Jan 1993.

[redacted]

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